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The oscillation-outbreaks characteristic of the COVID-19 pandemic

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SARS-CoV-2 has been circulating in the human population for more than a year and has caused over 150 million cases globally as of May 1st, 2021. Although a lot of regions have relied on measures such as social-distancing, contact-tracing, and quarantine to slow its spread [1], multidisciplinary researchers are actively engaged in understanding the dynamic of its transmission. The accurate prediction of the COVID-19 pandemic is foundational to guiding the public health policy-making and alleviating the socio-economic consequences [2–3]. Since the beginning of the outbreak, numerous studies have used diverse techniques to assess the disease transmission dynamics and predict its future course [2–4]. However, these modeling results have shown a wide range of variations. Fundamental improvements on the prediction require a deeper and wider understanding of the transmission dynamics under both human interventions and environmental influence. In this study, we provide an in-depth exploration on the periodicity and mutability in the evolutionary history of the COVID-19 pandemic and investigate the principle mechanisms behind them based on statistical and dynamical models.

The transmission of SARS-CoV-2 is regulated by various processes on multiple timescales. Isolating these processes on different timescales can help to identify the major inducements of the COVID-19 pandemic. We used the Ensemble Empirical Mode Decomposition (EEMD) method (Supplementary Section 1) to separately decompose the time series data of daily confirmed cases and deaths in the Northern and Southern Hemispheres (NH and SH). The time series data consist of the oscillations over weekly and seasonal timescales and the long-term trend that drives the increase in COVID-19 cases (Fig. 1b). The weekly oscillations for both hemispheres exhibit negative signals for confirmed and death cases during the weekend, while positive signals are exhibited in the middle of the weeks (Wednesday, Thursday and Friday, see Fig. S3). This can be explained by the distinct differences in human behavior patterns between weekdays and weekends, which may lead to a weekly cycle of contact rate, contributing to higher (lower) infection possibility during weekdays (weekends). Although this weekly pattern is consistent with the observed weekly oscillation of COVID-19 daily cases, the observed oscillation is

mainly attributable to the reporting bias, with higher rates of reporting during certain days of week [5]. A higher mortality reported during weekdays further supports this point since the weekly behavior pattern is unlikely to cause a higher mortality during weekdays (Fig. S3)

Seasonal modulation is another major factor that influences the dynamics of COVID-19 transmission. Using the EEMD method, decomposed oscillations on the seasonal time scale indicate higher infectivity and mortality in colder climates for both hemispheres, as shown in Fig. 1b (for decomposition of death cases please refer to Figs. S2 and S3). This result is consistent with both epidemiological and laboratory studies [6]. Seasonal variations in the meteorological and environmental factors can affect the COVID-19 transmission via their influence on the virus stability, host immunity and human behavior. However, the EEMD decomposition shows that the seasonal oscillations with limited amplitude are not able to reverse the long-term growing trend of the cases (Fig. 1b). Therefore, beneficial climate conditions (e.g. onset of higher temperatures during the warm seasons) should not be used as a criterion to decide on relaxing control measures [7–8].

The time series data of COVID-19 exhibit cyclical behavior due to the seasonal and weekly modulation, while its evolution is also regulated by some rapid growth periods (abbreviated as outbreaks hereafter). These abrupt shifts could be attributable to changes in the governmental response and public adherence, as well as the unexpected natural and socio-economic crisis. In either case, these incidents result in the higher risk of mass gathering, which directly leads to super-spreading events and the subsequent COVID-19 disaster. An anomaly detection algorithm (Supplementary Section 2) has identified 4 major outbreaks along the COVID-19 time series data, which are shaded in Fig. 1a. For each outbreak, we separately selected a hotspot region with a dominant contribution (Russia, US, Brazil and India) and attempted to provide causal explanations of these outbreaks based on the second version of the Global Prediction System for COVID-19 Pandemic (GPCP, v2, details in the supplementary material) [4].

Russia is among the four countries with the highest number of confirmed COVID-19 cases as of May 2020. However, during the first outbreak, the initial rise of the case counts in Russia happened later than many of the neighboring countries. This is possibly due to the effective implementation of the proactive non-pharmaceutical interventions (NPIs), which limited the virus import from Asian countries. Unfortunately, the Russian authority did not react quickly enough to prevent case importation from European countries, in which local transmissions had already occurred until mid-March 2020. As of March 15th, 74.2% of the inbound flights from other European countries were still operating (Fig. 1b). A recent genomic study has shown that most of the sampled sequences from Russia in the early stage are nested within other European subclades, which indicates multiple introductions of the virus from Europe [9]. Our simulation indicated that if travel restrictions were implemented 5 days earlier, 64.1% of the cases could have been avoided as of May 20th, 2020, as shown in Fig. 1c and Supplementary Section 3.1.

The United States has contributed more than 20% of the global reported cases during the first three outbreaks. Since the end of May 2020, a series of protests against police brutality and racism have been widespread in the US and many regions across the world. Mass gatherings and physical contact during the Floyd protests resulted in a significant increase in contact rates and susceptible supply (Fig. S10). Although the number of protests across the US has peaked in early June and steadily declined afterwards, the mass gatherings during the protests have caused a 52.2% increase in the total cases as of September 1st, 2020, as shown in Fig. 1d and Supplementary Section 3.2.

Sustained and intensive public health interventions have drastically disrupted almost entire sectors of society. As a result, signs of pandemic fatigue among policymakers and the public have emerged worldwide. For example, steady declines in the government stringency index have been recorded in Brazil and India since May 2020 [10], which almost coincided with upward trends of transmission rates before the significant rise of daily new cases (Figs. S12c and S13c). Pandemic fatigue among the public led to demotivated engagement in protection behaviors, which put them at a higher risk of infection. In India, religious celebrations and other social gatherings had been allowed, which pushed the reported daily cases to break the world's highest record. However, under the sustained public health interventions, the pandemic curves in Brazil and India could have been flattened, as shown in Figs. 1e-f and Supplementary Section 3.3.

The performed statistical analysis and dynamical simulations in this work both indicate multifaceted influences on COVID-19 transmission dynamics. We found limited weekly and seasonal modulations on COVID-19 evolution, while public behaviors and governmental decisions that determine the frequency of mass gathering were able to cause abrupt shifts in the daily new cases. If gathering activities could be accurately parameterized, then reliable predictions of the COVID-19 cases are achievable. Additionally, our study also highlights the decisive role of NPIs. Given the facts of emerging SARS-CoV-2 variants and unguaranteed effectiveness of the developed vaccines, NPIs remain one of the most effective measures to control the epidemic in the foreseeable future before high levels of vaccine-mediated protection can be achieved across the world.

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Declaration of interests

The authors declare no competing financial interests.

References

1. Z. Li, Q. Chen, L. Feng, L. Rodewald, Y. Xia, H. Yu, R. Zhang, Z. An, W. Yin, W. Chen, Y. Qin, Z. Peng, T. Zhang, D. Ni, J. Cui, Q. Wang, X. Yang, M. Zhang, X. Ren, D. Wu, X. Sun, Y. Li, L. Zhou, X. Qi, T. Song, G. F. Gao, Z. Feng, Z. Li, Q. Chen, L. Feng, L. Rodewald, Y. Xia, H. Yu, R. Zhang, W. Yin, D. Ni, Y. Qin, T. Zhang, J. Cui, Q. Wang, X. Yang, M. Zhang, W. Chen, Z. Peng, X. Ren, Z. An, D. Wu, X. Sun, Y. Li, L. Zhou, X. Qi, G. F. Gao, Z. Feng, T. Song, H. Luo, Z. Yin, L. Wang, C. Ma, & S. Li, Active case finding with case management: the key to tackling the COVID-19 pandemic. *The Lancet*, **396** (2020) 63–70. [https://doi.org/10.1016/S0140-6736\(20\)31278-2](https://doi.org/10.1016/S0140-6736(20)31278-2).
2. Z. Yang, Z. Zeng, K. Wang, N. Zhong, & J. He, Scientific guidance to fight the pandemic: the Coronavirus Disease 2019 (COVID-19). *Journal of Thoracic Disease*, **13** (2021) 505–510. <https://doi.org/10.21037/jtd-2021-02>.
3. Z. Yang, Z. Zeng, K. Wang, S. S. Wong, W. Liang, M. Zanin, P. Liu, X. Cao, Z. Gao, Z. Mai, J. Liang, X. Liu, S. Li, Y. Li, F. Ye, W. Guan, Y. Yang, F. Li, S. Luo, Y. Xie, B. Liu, Z. Wang, S. Zhang, Y. Wang, N. Zhong, & J. He, Modified SEIR and AI prediction of the epidemics trend of COVID-19 in China under public health interventions. *Journal of Thoracic Disease*, (2020). <https://doi.org/10.21037/jtd.2020.02.64>.
4. J. Huang, L. Zhang, X. Liu, Y. Wei, C. Liu, X. Lian, Z. Huang, J. Chou, X. Liu, X. Li, K. Yang, J. Wang, H. Liang, Q. Gu, P. Du, & T. Zhang, Global prediction system for COVID-19 pandemic. *Science Bulletin*, (2020). <https://doi.org/10.1016/j.scib.2020.08.002>.
5. J. Dehning, J. Zierenberg, F. P. Spitzner, M. Wibral, J. P. Neto, M. Wilczek, & V. Priesemann, Inferring change points in the spread of COVID-19 reveals the effectiveness of interventions. *Science*, **369** (2020) eabb9789. <https://doi.org/10.1126/science.abb9789>.
6. Z. Huang, J. Huang, Q. Gu, P. Du, H. Liang, & Q. Dong, Optimal temperature zone for the dispersal of COVID-19. *Science of The Total Environment*, **736** (2020) 139487. <https://doi.org/10.1016/j.scitotenv.2020.139487>.
7. WMO, *First Report of the WMO COVID-19 Task Team: Review on Meteorological and Air Quality Factors Affecting the COVID-19 Pandemic* (2021).
8. X. Liu, J. Huang, C. Li, Y. Zhao, D. Wang, Z. Huang, & K. Yang, The role of seasonality in the spread of COVID-19 pandemic. *Environmental Research*, **195** (2021) 110874. <https://doi.org/10.1016/j.envres.2021.110874>.
9. A. B. Komissarov, K. R. Safina, S. K. Garushyants, A. V. Fadeev, M. V. Sergeeva, A. A. Ivanova, D. M. Danilenko, D. Lioznov, O. V. Shneider, N. Shvyrev, V. Spirin, D. Glyzin, V. Shchur, & G. A. Bazykin, Genomic epidemiology of the early stages of the SARS-CoV-2 outbreak in Russia. *Nature Communications*, **12** (2021) 649. <https://doi.org/10.1038/s41467-020-20880-z>.
10. T. Hale, N. Angrist, R. Goldszmidt, B. Kira, A. Petherick, T. Phillips, S. Webster, E. Cameron-Blake, L. Hallas, S. Majumdar, & H. Tatlow, A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker). *Nature Human Behaviour*, **5** (2021) 529–538. <https://doi.org/10.1038/s41562-021-01079-8>.

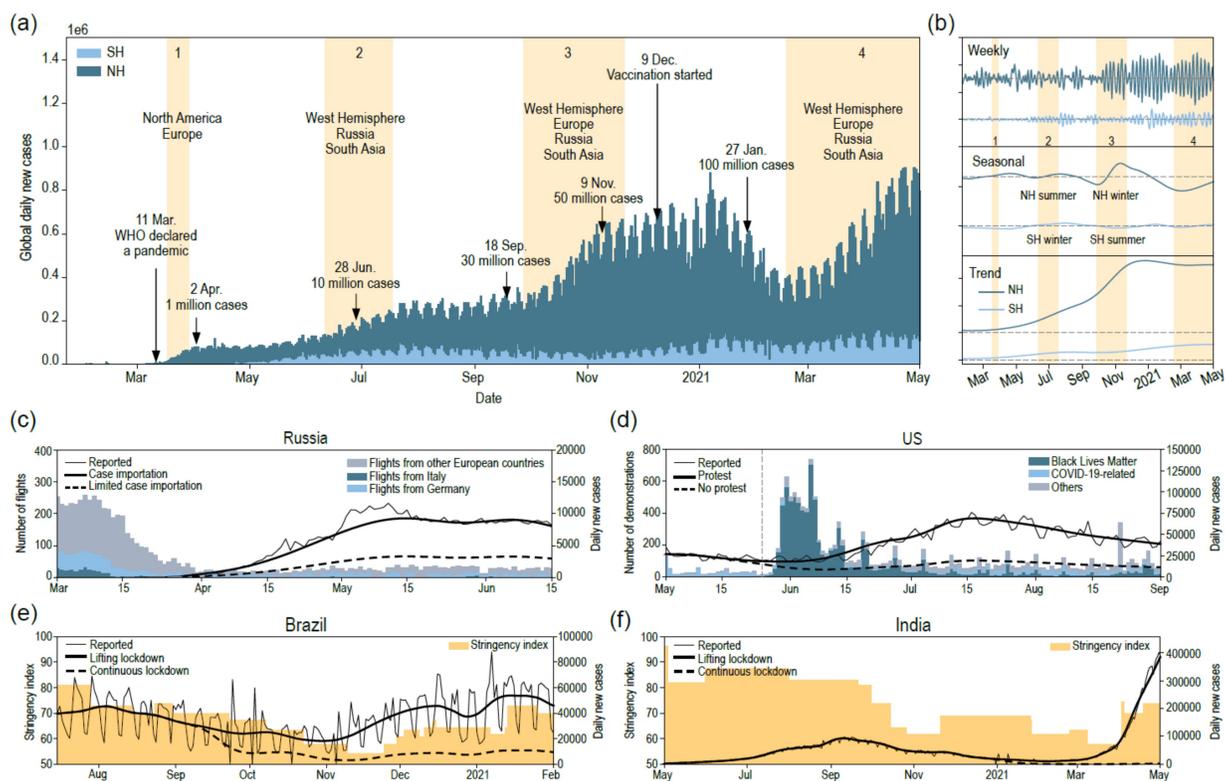


Figure 1. The evolution of the COVID-19 pandemic. (a) The global daily new cases, with deep (light blue) denoting the cases in the Northern (Southern) Hemisphere. (b) The weekly, seasonal and trend components decomposed by the EEMD method. (c)~(f) show the scenario simulations in Russia (c), US (d), Brazil (e) and India (f). The thin dashed black lines in (c)~(f) denote the reported daily new cases in each country, while the thick solid and dashed lines denote the simulation in two different scenarios.

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